The Mean Hourly Global Radiation Prediction Models Investigation in Two Different Climate Regions in Morocco

R. Mejdoul*‡, M. Taqi**

*Faculté des Sciences Ben M'sik, Université Hassan II Mohammedia

rachidmejdoul@yahoo.fr, moha_taqi@yahoo.fr

‡ Corresponding Author; R. Mejdoul, Avenue Cdt Driss El Harti, B.P. 7955, Ben M'Sik, 20800 Casablanca, MAROC, +212 6 14 44 14 88, rachidmejdoul@yahoo.fr

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Abstract- In last recent decades, Morocco gives increasing interest to developing renewable energy, by offering a wide range of investment opportunities in the sector of thermal solar energy. To establish such technology, predicting hourly radiation received during an average day of the month is mostly imperative. This paper proposes a statistical comparison between measured data of mean hourly global radiation at two different climate regions located in Morocco and three predicting models. This study is based upon statistical indicators which are root mean square error (RMSE), mean bias error (MBE) and correlation coefficient (R). It is attested that the Collares-Preira and Rabl correlation as modified by Gueymard (CPRG) fits more closely the measured data in this two regions at the West (Casablanca) and the East (Ouarzazate) sides of Atlas Mountains. Collares-Preira and Rabl model (CPR) gives practically the same result as CPRG but the correlation given by Whillier Liu and Joradan (WLJ) under-estimates the measured values at solar noon.

Keywords- Statistical study; hourly global radiation; tow Moroccan regions.

1. Introduction

At the opposite of economic and population growth, the limitation of traditional energy resources particularly combustible one, revealed a serious development crisis. This situation gives more interest to other alternative solutions. Solar energy is one of promising natural resources, which raises a particular concern by its durability, abundance and cleanliness. Hourly solar radiation received at any point on the globe is very important to make adequate choice for solar platforms installation, simulation of solar energy processes, sizing thermal storage, etc... Unfortunately, this parameter is rarely measured at few locations in Morocco, especially in few meteorological stations, reason for which one have to estimate the hourly global irradiation at a given site.

The total amount of solar energy depends upon the season of the year and sky conditions during day time. Since 1950s, enough work has been done in this way worldwide. Using monthly average data from available measuring points and statistical distribution of the total radiation on horizontal surfaces along the day led to generalized charts of the ratio (r) of hourly total (I) to daily total (H) radiation on horizontal surfaces. Whillier (1956) [1] introduced the 'utilisability' method to predict analytically the performance of active solar collectors. This method used a simple formulation to estimate the mean hourly radiation during each hour of an average day of the month, based on the ratio of the hourly to daily irradiation received by a horizontal surface outside of the atmosphere. Collares-Preira and Rabl (hereafter, CPR) [2] re-examined the correlations, initiated by Liu and Jordan (hereafter, WLJ) [3], between diffuse and global and between hourly and daily values of insolation. CPR confirmed Liu and Jordan approach, they realized that the atmospheric attenuation of direct and global radiation had dependency upon hour angle and therefore they proposed a new correlation based on Liu and Jordan original equations which assumed no atmospheric effect. Gopinanathan [4] attested the applicability of CPR model to Southern Africa for six locations in Lesotho, by comparing estimated and measured data for two locations in South Africa. Srivastava [5] compared WLJ, CPR and Garg and Garg [6] correlations with measured data at Lucknow in India. This author confirmed the adaptability of CPR model. Soler and Gopinathan [7] tested Liu and Jordan equation to estimate monthly mean hourly to daily diffuse ratio (rd) and tested its applicability in Spain locations. They attested that this estimation increases rapidly as one approaches high hour angles away from solar noon. To overcome this inconsistency, they adjusted a second-order polynomial equations relating rd and the monthly mean daylength S0. Gueymard [8] proposed a slight correction to the CPR model (hereafter, CPRG) to make it internally consistent. He also showed that morning-afternoon asymmetries could limit the accuracy of the predicted mean hourly radiation. This model was also used by Armstrong [9] to perform a new methodology for optimizing solar energy extraction over tilt angle panel under cloudy conditions. Gabriel Lopez [10] developed and tested a simple parametric model, based on combined geometrical and physical parameters, to estimate daily values of horizontal global solar radiation under cloudless conditions. This model has given a good level of accuracy when compared with measured data. Later, Huashan Li [11] proposed a new empirical model for estimating daily global solar radiation under highly variable weather conditions. S. Alam [12] compared WLJ and CPR models with second order polynomial fitting of measured data for six stations located in India. He showed that his correlation may be used as an alternative to CPR model.

The main objective of the present work is to reveal a suitable model predicting global mean hourly radiation in two locations in Morocco. For this purpose, a comparative study, based on statistical test errors as RMSE and MBE, between the measured data and the three models referenced above is conducted. The first site is located in Casablanca city, at the East side of Atlantic Ocean, with low topographic elevation (56 m above the sea level), is regarded as a representative of plain terrain with moderate climate. The second site is located in Ouarzazate city at the south-east slopes of Atlas Mountains, a complex terrain region with (1136 m above sea level) and characterized by semiarid climate. The last site will host one of more important thermo-solar project worldwide, so it provides more interest with a capacity of 500 MW.

2. Data

The data used here, for Casablanca, comes from the National climatological center, located at Casablanca (33°34' N; 07°40' W, altitude 56 m above sea level), which has a radiometric solar park using a large number of measuring devices of different types of radiation (global, diffuse, direct...) and atmospheric ozone parameter. Type Instrument KIPP & ZONEN CM11 sensitive to all or substantially all of the energy spectrum, calibrated in the laboratory of the WMO, intercepts different types of atmospheric radiation and convert them into a processed electrical signal at a string of acquisition type Cambell CR10X to store them on computer. For Ouarzazate, data are collected from meteorological automatic airport station. All hourly data for these two stations are plotted in Appendix A (Fig 1A for Casablanca and Fig 2A for Ouarzazate). Using this data set, long term monthly-mean hourly global radiation data are obtained from hourly global radiation, by averaging individual hourly values for each month over a period of eight years from 2000 to 2007 (for Casablanca) and ten years from 2000 to 2009 (for Ouarzazate). The long term monthly-mean daily global irradiation is obtained as the sum of each individual hourly irradiation for the given day.

3. Models

A. *Whilier, Liu and Jordan model (WLJ)*

In this model, global radiation is considered to follow the same hourly distribution as if there were no atmosphere. For an hourly interval, according to the present procedure, the extraterrestrial hour/daily ratio can be obtained simply as:

$$r_{WLJ} = \frac{(\pi/24)(\cos\omega - \cos\omega_0)}{\sin\omega_0 - \omega_0\cos\omega_0} \tag{1}$$

where $\omega = \pi(1 - t/12)$, t is the local apparent time of the middle point of each hourly period derived from the Equation of Time Eqt given by [13], and ω_0 is the sunrise hour angle (in radians) obtained by:

$$\omega_0 = -\tan\varphi\tan\delta \tag{2}$$

Here φ is the site latitude, δ is the solar declination obtained from Duffie and Beckman [13]:

$$\delta = 23.45\sin[360/365(284+n)] \tag{3}$$

where n is the day of the year by Julian calendar. Both δ and E_{qt} are given in “Table 1.” on monthly average value [8].

Table 1. Monthly average solar geometry: declination (δ. degrees) and Equation of Time (Eeq. minutes)

Months	Date	For average Day of Month		
		E_{qt}	n	δ
January	17	-9.97	17	-20.71
February	16	-14.54	47	-12.81
March	16	-9.36	75	-1.80
April	15	-0.22	105	9.77
May	15	3.75	135	18.83
June	11	0.57	162	23.07
July	17	-5.80	198	21.16
August	16	-3.88	228	13.65
September	15	5.68	258	02.89
October	15	14.97	288	-8.72
November	14	14.95	318	-18.37
December	10	10.25	344	-22.99

B. Collares-Pereira and Rabl

Collares-Pereira and Rabl give a significant improvement to correlation initiated by Whillier, Liu and Jordan by adding atmospheric effect as follows:

$$r_{CPR} = (a + b\cos\omega)\frac{(\pi/24)(\cos\omega - \cos\omega_0)}{\sin\omega_0 - \omega_0\cos\omega_0} \quad (4)$$

where a and b are linear functions of $\sin(\omega_0 - \pi/3)$ defined as:

$$a = 0.409 + 0.5016\sin(\omega_0 - \pi/3) \quad (4a)$$

$$b = 0.6609 - 0.4767\sin(\omega_0 - \pi/3) \quad (4b)$$

C. CPR model modified by C. Gueymard

The CPRG model consists in a slight modification to ensure consistency trough renormalization, the correlation is giving as:

$$r_{CPRG} = (a + b\cos\omega) r_{WLJ} / f \quad (5)$$

where

$$f = a + 0.5b(\omega_0 - \sin\omega_0\cos\omega_0)/A(\omega_0) \quad (6)$$

$$A(\omega_0) = \sin\omega_0 - \omega_0\cos\omega_0 \quad (7)$$

Measured values of radiation ratio are computed as:

$$r_{meas} = \frac{\bar{I}}{\bar{H}} \quad (8)$$

where

r_{meas} is the measured radiation ratio,

$\bar{I}$ is the measured monthly mean hourly global radiation and $\bar{H}$ is the measured monthly mean daily global radiation.

D. Comparison Method

In this study two statistical test, root mean square error (RMSE) and mean bias error (MBE), are used to evaluate the accuracy of the models described above.

The root mean square error is defined as

$$RMSE = \left\{\left[\sum\left(r_{i,calc} - r_{i,meas}\right)^2\right]/n\right\}^{1/2} \quad (9)$$

where $r_{i,calc}$ is the calculated value, $r_{i,meas}$ is the measured value, and n is the total number of observations. The RMSE is always positive, a zero value is ideal. The test provides information on the short-term performance of the models by allowing a term by term comparison of the actual deviation between the calculated value and the measured value. However a few large errors in the sum can produce a significant increase in RMSE.

The mean bias error is defined as:

$$MBE = \left[\sum\left(r_{i,calc} - r_{i,meas}\right)\right]/n \quad (10)$$

Where n is between 10 and 13 of daylight hour referring to seasonal period.

This test provides information on the long-term performance. A low MBE is desired. Ideally a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in separate observations. In addition to RMSE and MBE, the correlation coefficient (R) is used to assess the consistency how the models explain the observed variation. The correlation coefficient can be calculated using the following equation:

$$R = \frac{\sum(r_{i,calc} - r_{m,calc}).(r_{i,meas} - r_{m,meas})}{\sqrt{\sum(r_{i,calc} - r_{m,calc})^2 . \sum(r_{i,meas} - r_{m,meas})^2}} \quad (11)$$

where $r_{m,meas}$ and $r_{m,calc}$ are are the average of the measured and calculated values respectively.

4. Methodology

The collected data of hourly hemispherical insolation are used in this paper to calculate the measured hourly to daily radiation ratio as follows:

$$r_0 = \bar{I}/\bar{H} \quad (12)$$

$\bar{I}$ is the measured monthly mean hourly global radiation, calculated by averaging data at a given hour of the month over all the considered period of years.

$\bar{H}$ is the measured monthly mean daily global radiation, calculated by averaging data at a giving day of the month over all the considered period of years.

For this purpose, a FORTRAN program was developed to compute the theoretical values as it is explained above by the three correlations given by Liu and Jordan, Collares-Preira and Rabl and by CPRG as modified by Gueymard. A flowchart program explaining the sequences of this program is shown in the Appendix B.

5. Results and Discussion

Both measured and estimated radiation ratio for Casablanca (33°34' N, 07°40' W; 56 m) and Ouarzazate (30°56'N, 06°54'W; 1136 m) are plotted for each month of the year from January to December by the OriginLab-Pro software. All curves are displayed on “Fig.1 to Fig.12” for Casablanca and “Fig.13 to Fig.24” for Ouarzazate. Measured data are represented in all figures by solid line in tile, WLJ model in thick dot, CPR model in up full triangle and CPRG down full triangle. The time indicated in figures ranges between seven AM and seventeen PM (local time) with one hour rather or later according to summer or winter period. The first note for all figures is that all models represent closely the measured data before and after solar noon time. It can be observed that CPR and CPRG correlations represent tightly measured data at the opposite of WLJ correlation which underestimates data at solar noon time. Solar noon asymmetries are slightly remarkable in summer period for April to September months, for Casablanca site (see "Fig.4 to Fig.9"), at the opposite of the winter period where these asymmetries practically disappear (see "Fig.1 to Fig.3" and "Fig.10 to Fig.12").

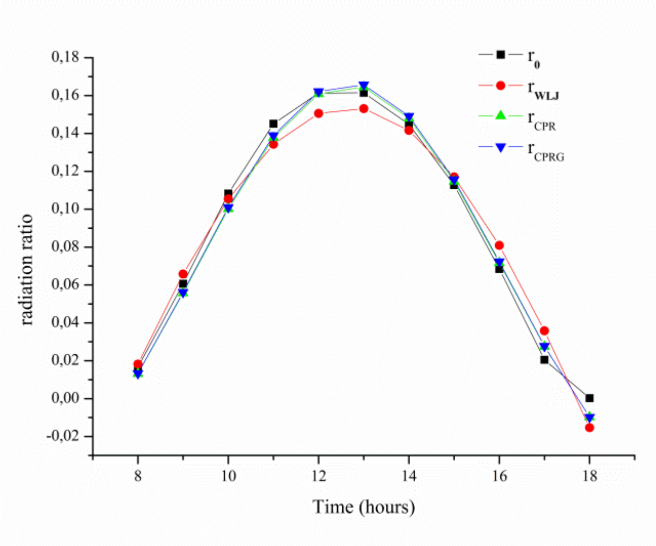

Fig. 1. Measured and estimated global radiation ratio for the month of January.

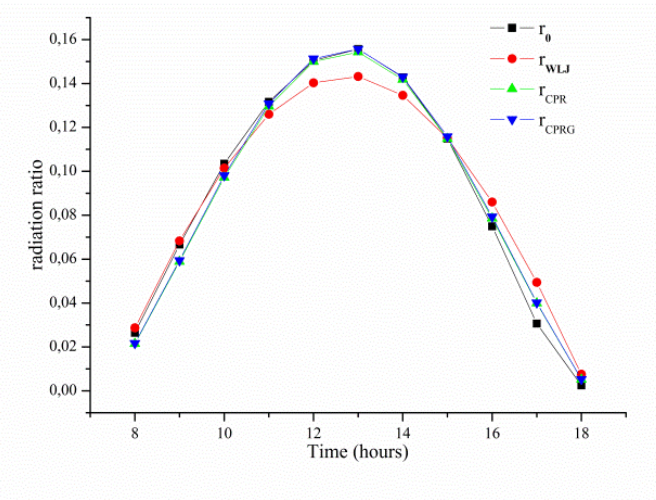

Fig. 2. Measured and estimated global radiation ratio for the month of February.

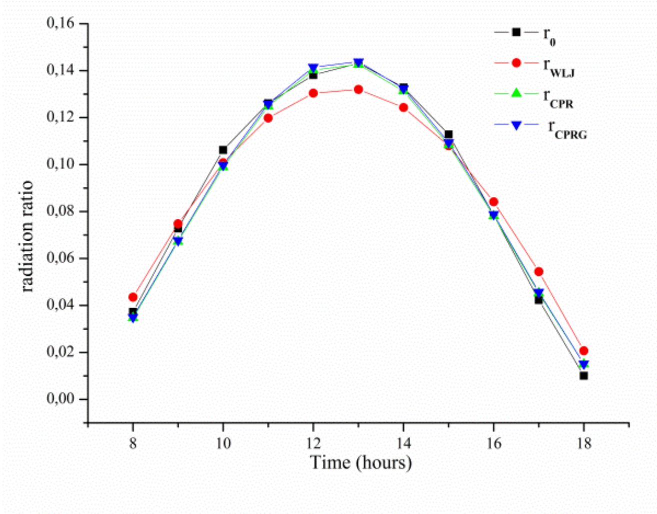

Fig. 3. Measured and estimated global radiation ratio for the month of March.

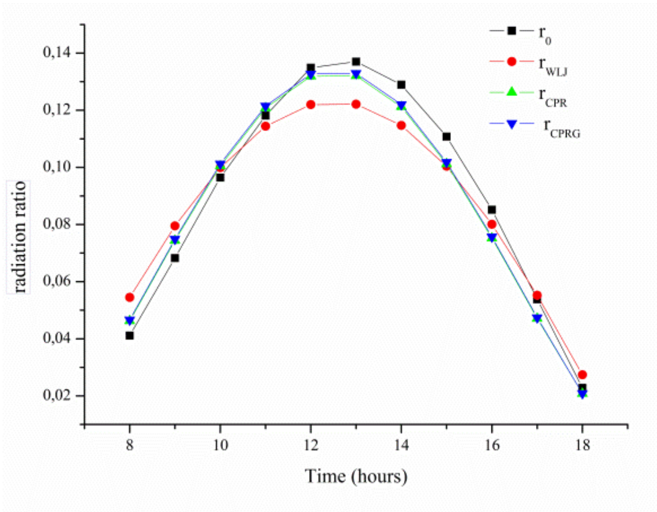

Fig. 4. Measured and estimated global radiation ratio for the month of April.

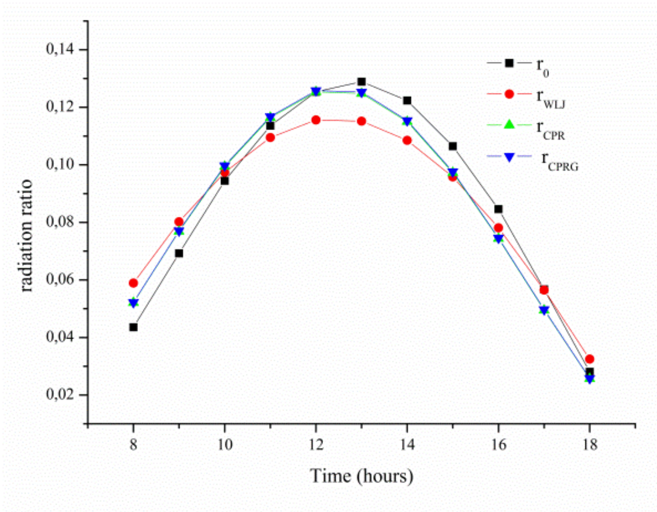

Fig. 5. Measured and estimated global radiation ratio for the month of May.

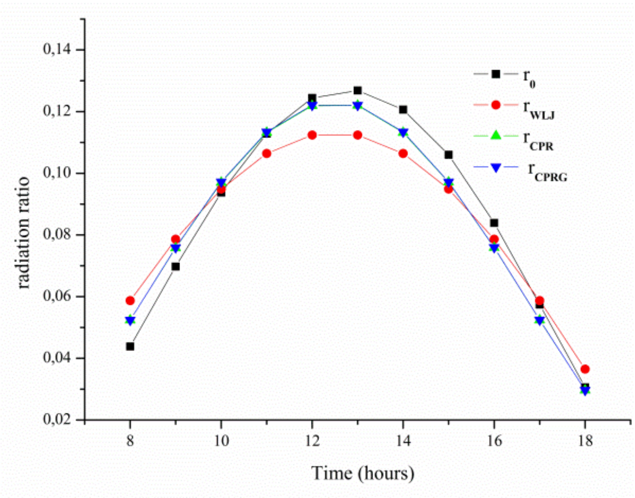

Fig. 6. Measured and estimated global radiation ratio for the month of June.

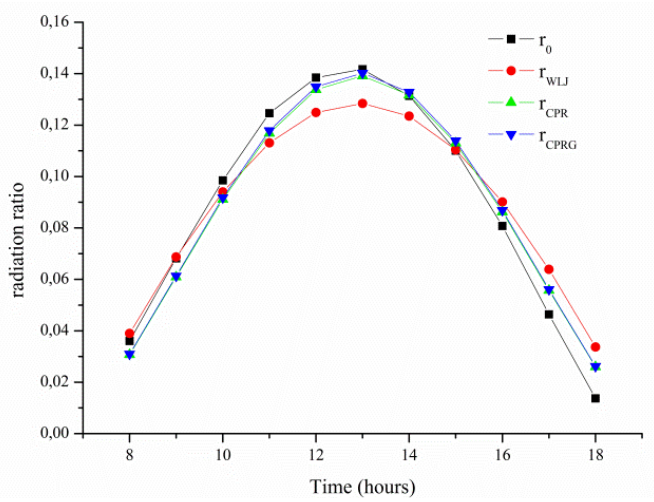

Fig. 9. Measured and estimated global radiation ratio for the month of September.

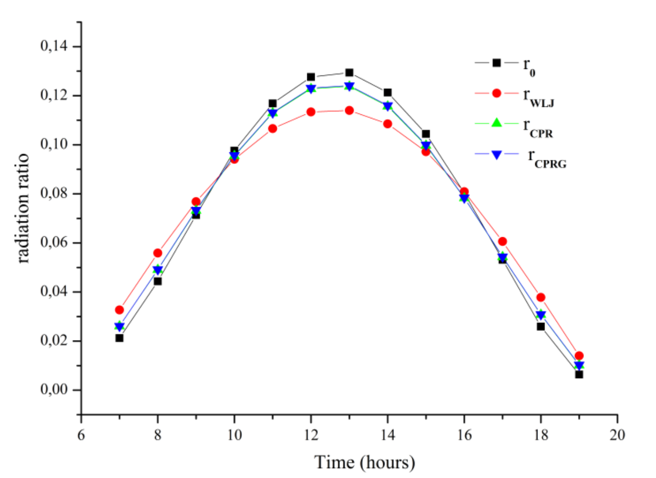

Fig. 7. Measured and estimated global radiation ratio for the month of July.

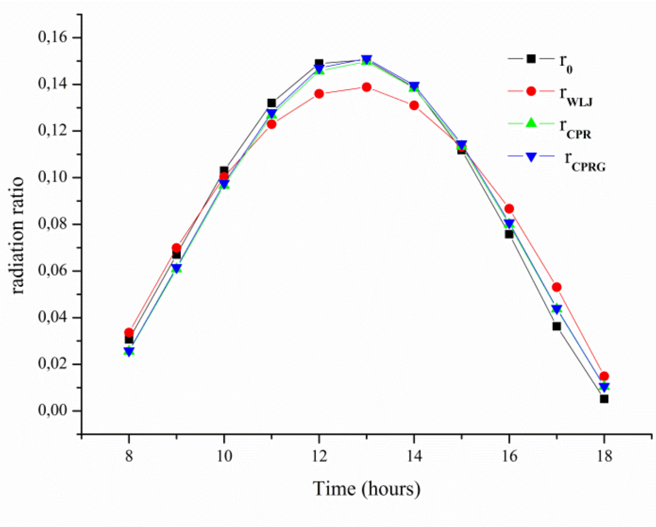

Fig. 10. Measured and estimated global radiation ratio for the month of October.

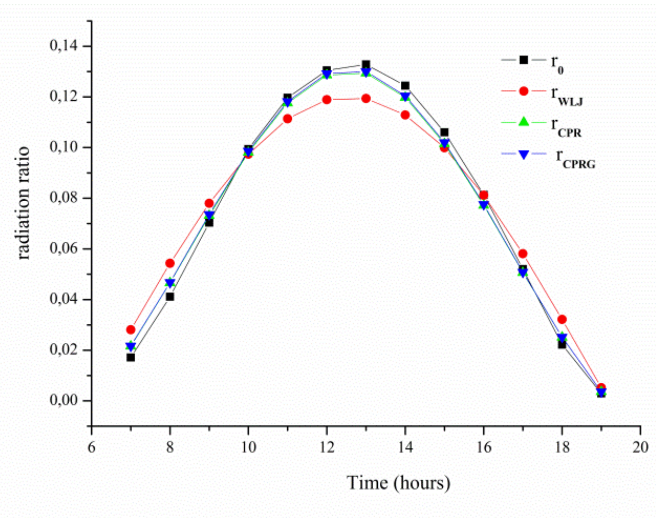

Fig. 8. Measured and estimated global radiation ratio for the month of Aout.

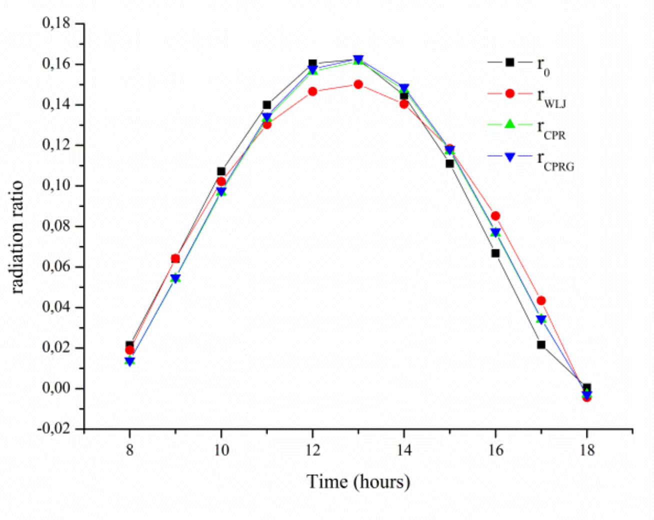

Fig. 11. Measured and estimated global radiation ratio for the month of November.

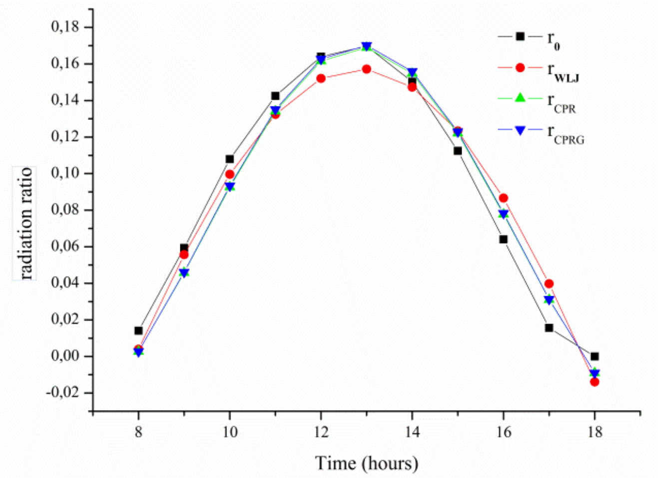

Fig. 12. Measured and estimated global radiation ratio for the month of December.

In the case of Ouarzazate site “Fig.13 to Fig.24” the same remarks can be made for summer time where theoretical and measured data are in close agreement with slight differences in July and August where CPR and CPRG models exceed lightly measured data at noon time. Low discrepancies are observed all of time between measured and theoretical values in low sun elevations (sunrise and sunset daytime). This later unconformity might be caused by optical phenomenon due to earth eccentricity or artifacts construction in the horizon.

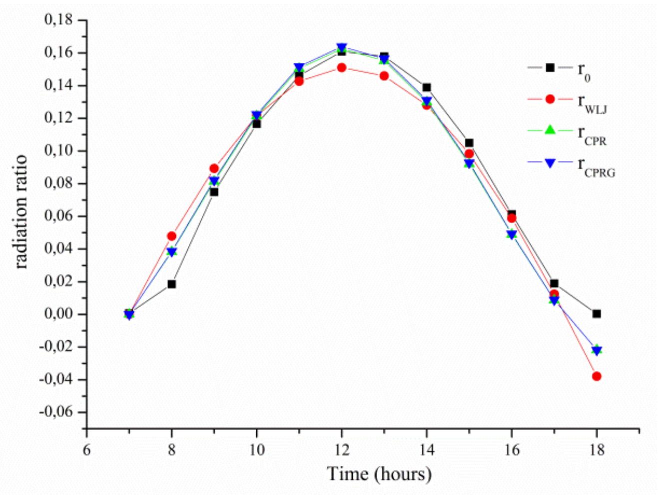

Fig. 13. Measured and estimated global radiation ratio for the month of January.

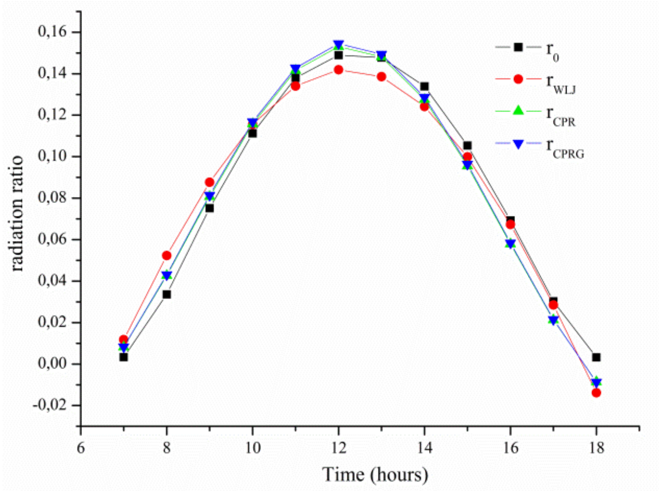

Fig. 14. Measured and estimated global radiation ratio for the month of February.

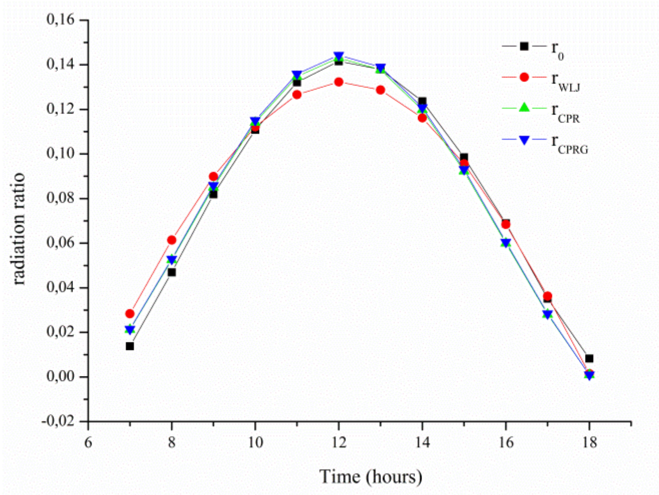

Fig. 15. Measured and estimated global radiation ratio for the month of March.

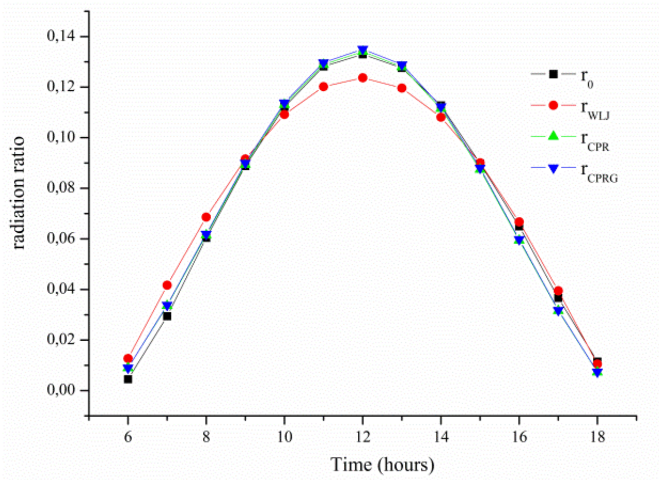

Fig. 16. Measured and estimated global radiation ratio for the month of April.

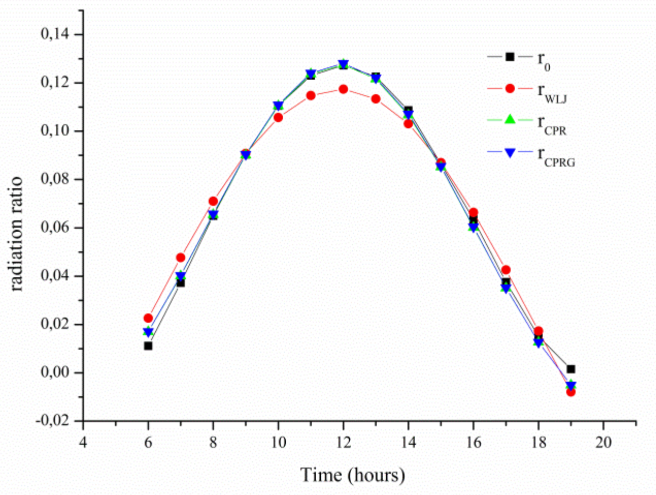

Fig. 17. Measured and estimated global radiation ratio for the month of May.

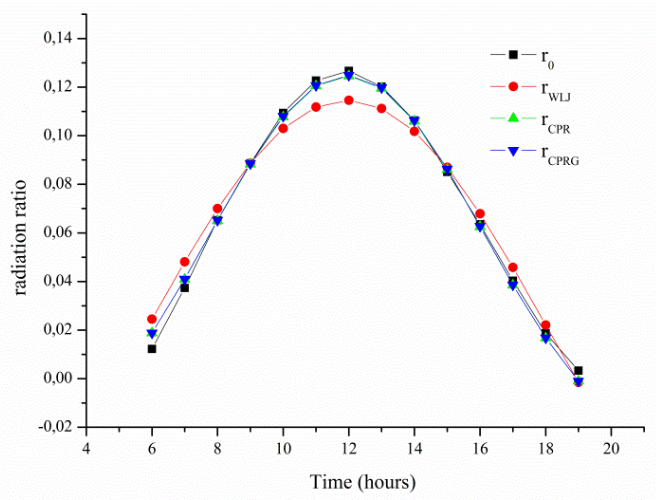

Fig. 18. Measured and estimated global radiation ratio for the month of June.

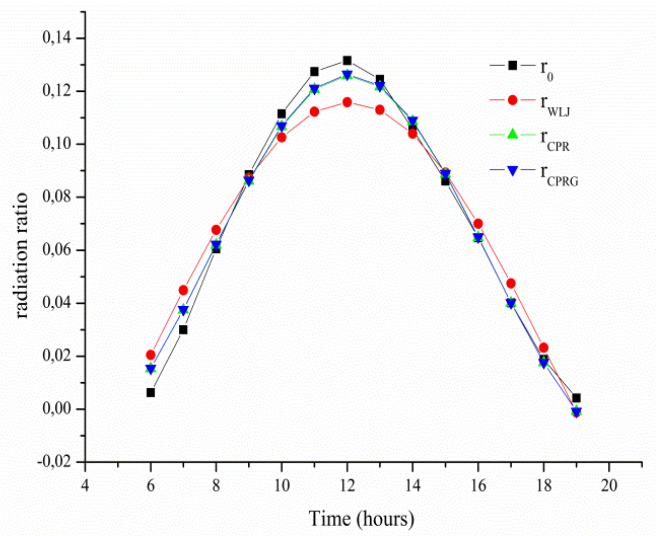

Fig. 19. Measured and estimated global radiation ratio for the month of July.

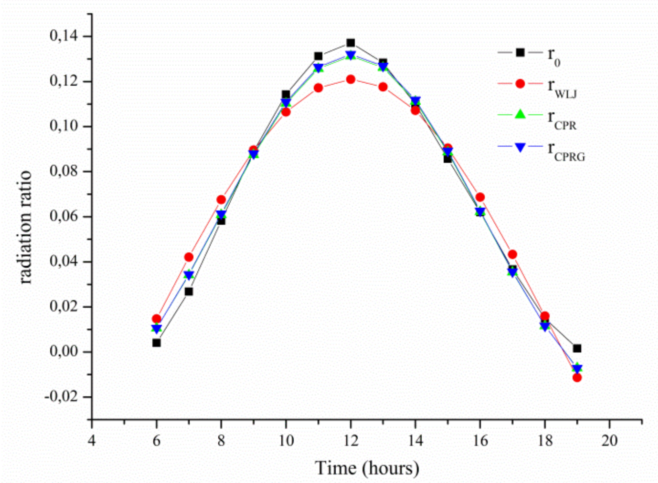

Fig. 20. Measured and estimated global radiation ratio for the month of Aout.

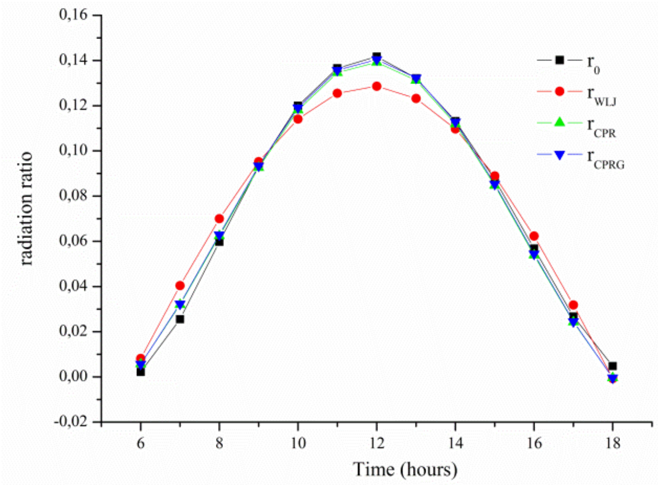

Fig. 21. Measured and estimated global radiation ratio for the month of September.

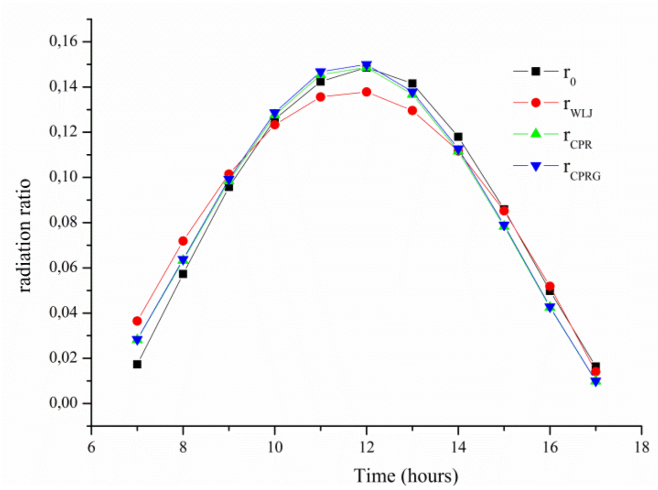

Fig. 22. Measured and estimated global radiation ratio for the month of October.

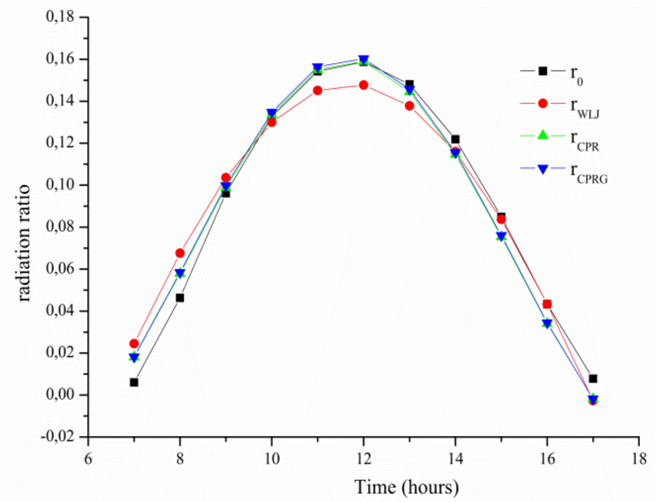

Fig. 23. Measured and estimated global radiation ratio for the month of November.

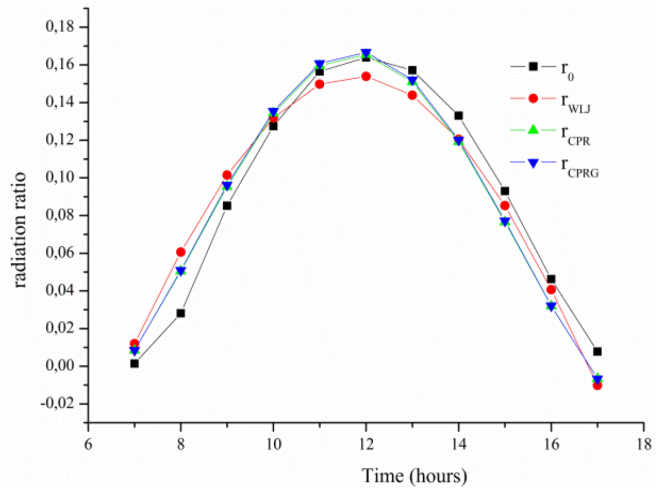

Fig. 24. Measured and estimated global radiation ratio for the month of December.

Referring to the results, summarizing the RMSE, MBE and correlations coefficients (R) values, showed in "Table 2." for Casablanca National Climatological Center and for Ouarzazate Meteorological Weather Station in "Table 3.". The performance of the above three models, "Fig.1 to Fig.7" are evaluated for the two sites, which represents separating sides of the Atlas Mountain chain with different geographical and climatic conditions. According to RMSE, MBE and (R) for Casablanca, for both CPR and CPRG models the values of RMSE and MBE for radiation ratio are still negligible (near zero), they don't exceed 0.007 (0.7%) and 0.0014 (0.14%) for RMSE and MBE respectively in summertime (from March to August) and they register a slit leap in winter (from September to February) with a maximum in November 0.025 (2.5%). The RMSE and MBE for radiation values of WLJ correlation are still lightly over those obtained with the previous models, a maximum in winter 0.037 (3.7%) and a minimum in summer 0.008 (0.8%). With terms of R the three correlations represent closely the measured data (all values exceed 0.96) with a good accordance given by CPR and CPRG models (all values reach 0.99).

With regard of the obtained results for Ouarzazate by means of CPR and CPRG, the values of RMSE for radiation ratio are less than a minimum of 0.0023 (0.23%) in summer and don't surpass a maximum of 0.012 (1.2%) in winter. The MBE values they draw near zero. Otherwise the RMSE and BME values obtained by WLJ correlation register their highest value in December 0.014 (1.4%) and 0.0008 (0.08%), oppositely they become near 0.007 (0.7%) and 0.0001 (0.01%) in May respectively. In terms of correlation coefficient R all values go over 0.98 for the three models. In summary all models gives best result mutually in Casablanca and Ouarzazate with more satisfactory result by CPR and CPRG models for all months in terms of RMSE and MBE. Hence these two last models give close results in comparison to WLJ model. So we can use CPRG with high accuracy followed by CPR both in east side of Atlas Mountain (Ouarzazate region) with hilly terrain and in west side (Casablanca) plain terrain.

Table 2. Root Mean Square Error (RMSE). Mean Bias Error (MBE) and Correlation Coefficient (R) between predicted and measured hourly irradiation for Casablanca site.

		WLJ	CPR	CPRG
January	*RMSE*	0.0095	0.0055	0.0055
	MBE	-0.0012	-0.0014	-0.0007
	R	0.9872	0.9960	0.9960
February	*RMSE*	0.0089	0.0046	0.0045
	MBE	0.0001	-0.0008	0.0001
	R	0.9929	0.9962	0.9962
March	*RMSE*	0.0079	0.0037	0.0035
	MBE	-0.0007	-0.0012	-0.0005
	R	0.9966	0.9966	0.9966
April	*RMSE*	0.0101	0.0061	0.0059
	MBE	-0.0013	-0.0017	-0.0012
	R	0.9888	0.9910	0.9910
May	*RMSE*	0.0099	0.0065	0.0064
	MBE	-0.0007	-0.0007	-0.0005
	R	0.9827	0.9880	0.9880
June	*RMSE*	0.0090	0.0054	0.0053
	MBE	-0.0029	-0.0014	-0.0013
	R	0.9864	0.9912	0.9911
July	*RMSE*	0.0101	0.0041	0.0040
	MBE	-0.0006	-0.0006	-0.0004
	R	0.9948	0.9995	0.9995
August	*RMSE*	0.0090	0.0034	0.0032
	MBE	-0.0002	-0.0006	0.0002
	R	0.9931	0.9986	0.9986
September	*RMSE*	0.0105	0.0068	0.0067
	MBE	-0.0010	-0.0012	-0.0005
	R	0.9826	0.9877	0.9877
October	*RMSE*	0.0127	0.0104	0.0103
	MBE	-0.0009	-0.0014	-0.0005
	R	0.9665	0.9705	0.9704
November	*RMSE*	0.0367	0.0250	0.0248
	MBE	0.0000	-0.0008	0.0000
	R	0.9827	0.9881	0.9881
December	*RMSE*	0.0134	0.0108	0.0108
	MBE	-0.0002	-0.0008	-0.0002
	R	0.9735	0.9813	0.9813

Table 3. Root Mean Square Error (RMSE). Mean Bias Error (MBE) and Correlation Coefficient (R) between predicted and measured hourly irradiation for Ouarzazate site.

		WLJ	CPR	CPRG
January	*RMSE*	0.0119	0.0095	0.0095
	MBE	-0.0003	-0.0009	-0.0002
	R	0.9805	0.9805	0.9861
February	*RMSE*	0.0089	0.0070	0.0070
	MBE	0.0005	-0.0004	0.0004
	R	0.9892	0.9901	0.9901
March	*RMSE*	0.0082	0.0054	0.0055
	MBE	-0.0002	-0.0008	-0.0001
	R	0.9877	0.9936	0.9936
April	*RMSE*	0.0065	0.0031	0.0031
	MBE	0.0002	-0.0004	0.0001
	R	0.9949	0.9976	0.9976
May	*RMSE*	0.0069	0.0024	0.0023
	MBE	0.0001	-0.0002	0.0001
	R	0.9961	0.9983	0.9983
June	*RMSE*	0.0076	0.0025	0.0024
	MBE	0.0000	-0.0001	0.0001
	R	0.9957	0.9985	0.9985
July	*RMSE*	0.0099	0.0046	0.0045
	MBE	0.0002	0.0000	0.0003
	R	0.9929	0.9967	0.9967
August	*RMSE*	0.0096	0.0041	0.0039
	MBE	0.0003	-0.0002	0.0002
	R	0.9912	0.9972	0.9972
September	*RMSE*	0.0084	0.0029	0.0027
	MBE	0.0002	-0.0004	0.0003
	R	0.9950	0.9987	0.9987
October	*RMSE*	0.0094	0.0060	0.0059
	MBE	0.0000	-0.0008	0.0000
	R	0.9879	0.9921	0.9921
Novembre	*RMSE*	0.0110	0.0101	0.0072
	MBE	0.0007	0.0001	0.0007
	R	0.9907	0.9901	0.9901
December	*RMSE*	0.0142	0.0119	0.0119
	MBE	0.0142	0.0188	0.0119
	R	0.9749	0.9765	0.9765

6. Conclusion

This paper evocates a comparative study between measured data and the three correlations (WLJ, CPR and CPRG) by mean of statistical indicators such as the root mean square error (RMSE), the mean bias error (MBE) and the correlation coefficient (R). This study has been conducted for two economically important and separate climate regions in Morocco, mainly Ouarzazate city where the first important solar-thermal field (500 MW) in Africa will be located. This work allowed, for the first time in Morocco, to validate Liu and Jordan, Collares-Pereira and Rabl and CPRG as modified by Guyemard models with long term hourly global radiation data set. It is found that CPRG and CPR models can be used with perfect accuracy in two sides of Atlas Mountain and nearby regions to estimate hourly global radiation on a horizontal surface. Moreover, this study showed the disagreement between estimated and measured data at low solar angles and solar noon asymmetries as mentioned by several authors.

7. Appendix.

A. Hourly Plotting Measured Data.

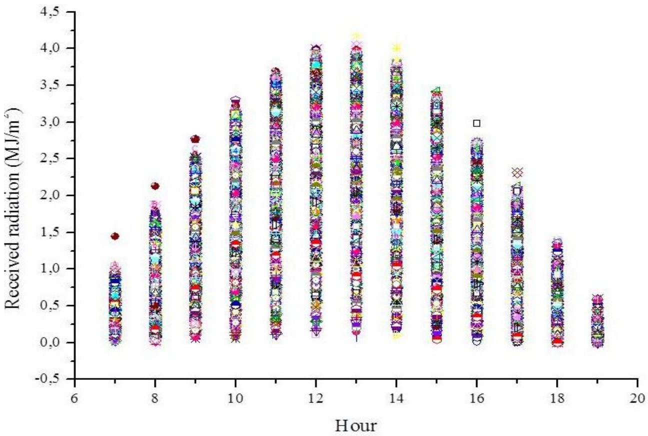

Fig. A1. Casablanca measured hourly radiation used data (2000-2007) plotting.

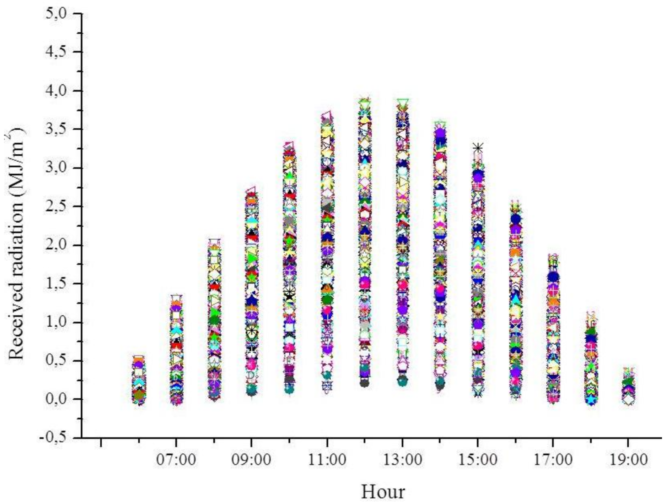

Fig. A2. Ouarzazate measured hourly radiation used data (2000-2009) plotting.

B. Flowchart Program.

In the flowchart program below explain how the developed model activity should been executed. The first step, we start by fixing the site geographical coordinates (latitude λ, Longitude ψ) and the given month. After, δ and Eqt are calculated then the angle hour is calculated for each local time hour. Finally, the radiation ratios given by the three models (WLJ, CPR and CPRG) are calculated and the global mean hourly radiation is then deduced. This sequence is repeated for the 12 months.

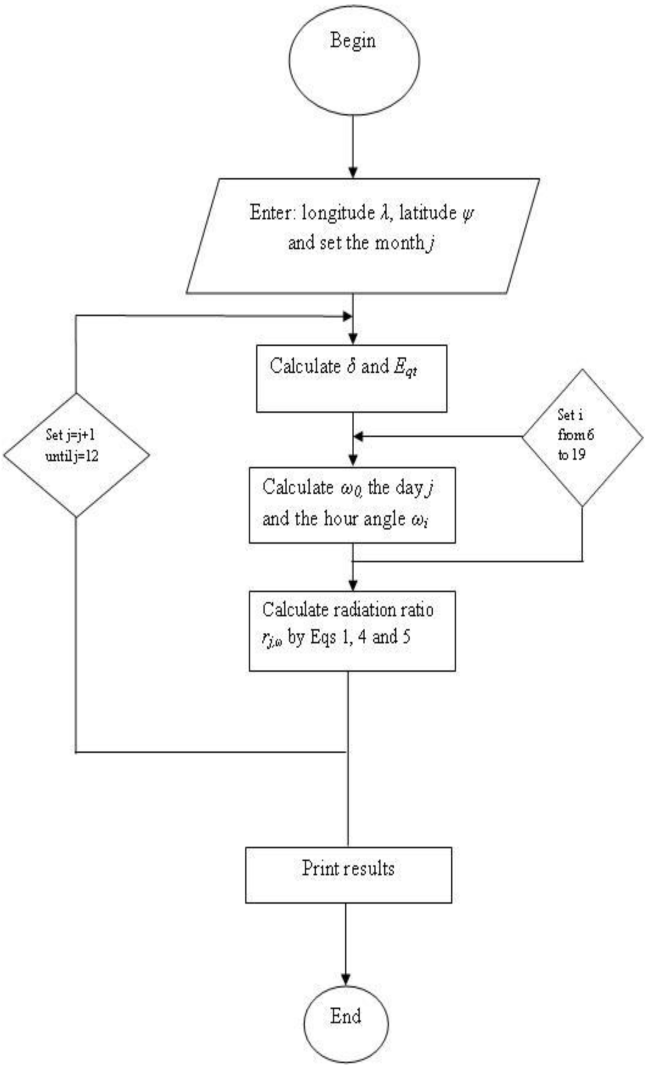

Fig. B. Flowchart program for calculating the radiation ratio.

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